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September 19, 2007

Eric Becker
CRWQCB
9174 Sky Park Court, Suite 100
San Diego, CA 92123

John Odermatt
CRWQCB
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Re: ADDITIONAL INFORMATION SUBMITTAL for INVESTIGATIVE ORDER NO. R9-2007-0060, DISCHARGE OF UNTREATED SEWAGE INTO BUENA VISTA LAGOON WITHIN THE CITY OF CARLSBAD, SAN DIEGO COUNTY (Reference: NCRU:01-0743.02 & 01-0764.02:ebecker)

Dear Eric and John:

The Cities of Vista and Carlsbad (Cities) remain interested in scheduling a meeting with Board staff as expeditiously as your schedules will allow in order to address any questions you may have regarding previously submitted materials. Please let us know how we may best assist in coordinating such a meeting.

In Section 4.9 of the April 23, 2007 Investigative Order No. R9-2007-0060 Response (IO Response), the Cities identified opportunities to explore aspects of: 1) Discharge Avoidance; 2) Leak Detection; 3) Response Time and Resources; and 4) Impact Minimization and Recovery.

This document serves as a report on our progress in those areas and a supplemental information submittal to the IO Response. As you will gather from this submittal, the Cities continue to investigate opportunities to enhance their capabilities with respect to discharge avoidance, detection, and response. Some substantial progress has been made, and we believe reporting on that progress at the present time would be beneficial in supporting the Board's consideration of future actions.

In addition, when we submitted the IO Response, we noted that some investigations were ongoing, particularly with regards to the causes of force main failure and environmental harm. We have previously submitted additional information with respect to dissolved oxygen recovery in the system, bacteria level decline rates and recovery of natural sediment bacteria levels, and progress towards upland habitat restoration actions. There have been no additional losses of birds, fish, or invertebrates that we are aware of subsequent to the initially reported losses that occurred coincident with the spill event, and there have been no noted secondary algal blooms or indications of avian illnesses that we are aware of.

We now have the final corrosion report, and the Cities have had a chance to review this document. The Schiff report provided some disconcerting news regarding the lack of ability to further assess risks to the pipeline and indicated that other areas may be at similar risk of failure. While the Schiff report does not indicate that other pipeline failures are imminent, it does highlight the lack of capacity to determine the integrity of the pipeline relative to corrosion failure risks. We are hereby transmitting this document, along with the Cities' intended response to the findings from the report.

CORROSION INVESTIGATION AND RESPONSE

Schiff Associates Report

Schiff Associates, corrosion experts, conducted an analysis of the failure incident at the request of the Cities. The full final report of this analysis is attached. The Schiff report concluded that although the pipeline was installed with industry standard methods at the time, the fact that the polyethylene (PE) liner had been breached by an unknown cause, potentially at the time of construction, and that the pipe is located in corrosive soils, the pipeline may be at risk of other undetectable failures of a similar nature. The report suggests lining the pipe with high-density polyethylene (HDPE) or cured-in-place polyurethane (CIPP), or alternatively, cathodically protecting the pipe by electrically connecting each joint. This would require shoring, dewatering, and excavating at every joint and brazing cable connections across each pipe joint. Due to the potential for significant environmental impacts, the potential to do damage to the existing pipeline, impracticality of some of the options, and the high cost of remaining activities, these alternatives have been deemed too risky to pursue.

The Schiff Associates report also noted that the pipe could be replaced. Given the present standards, ductile iron pipe (DIP) would require more than PE encasement for the corrosivity of the soils. It was also noted that alternative materials to DIP such as HDPE might be a possibility for replacement.

Under the existing City of Carlsbad's Sewer Master Plan, the replacement of the pipeline was scheduled to be within their 2017 Wastewater CIP. This would mean that the principal capital replacement costs would be realized in 2017, 15 years ahead of the 50-year anticipated planned lifespan for the pipeline. To meet this schedule, however, work on design, environmental analysis, and permitting would commence in 2014 along a 3-year course prior to construction.

Based on the Schiff Associates Revised Final Report present findings, the Cities are moving forward with a replacement of the pipe on the earliest possible scheduled timeframe. With the City of Carlsbad as the responsible agency for maintenance and replacement of the pipeline, the Cities have re-scoped their original Capital Improvement Program (CIP) project for the construction of a parallel additional 24-inch pipeline to include the internal lining of the existing 24-inch pipeline. The Carlsbad City Council approved the preliminary design report, environmental review, permits, final design, plans, and specifications for the re-scoped project on September 11, 2007. As a part of the Carlsbad City Council's action, the noted portion of the re-scoped project was moved forward to the current fiscal year (FY 2007-2008) CIP Program. This means that work on planning and preliminary design will commence this FY 2007-2008. Contracting for construction will be funded and scheduled after the design and environmental work is completed.

While there is presently no indication that the pipeline is corroding or otherwise likely to experience a localized failure again short of its anticipated lifespan, the Cities deem action towards an expedited replacement to be prudent. If, however, along the course of project investigation, it is determined that additional failures are eminent, or in the event of an additional failure of the line, acceleration of work along a standard CIP schedule implementation may be altered to an emergency action level, thus short cutting much of the normal process.

Having received the Revised Final Report from Schiff Associates noting the possible condition of the entire pipeline, the City of Carlsbad has escaladed the frequency of visual inspections to once a week to enhance possible detection of a leak until a new line is installed and the existing pipe is lined. The City of Carlsbad is now conducting a walking inspection of the entire length of the Buena Vista Force main from the lift station up to the I-5 Bridge on a daily basis. Carlsbad staff has been instructed to report and respond to leaks and/or suspicious conditions. The City of Carlsbad has also been contracting with Sub-Surface Surveys to assist with locating a buried valve on the force main on Jefferson adjacent to the I-5.

PROGRESS ON PROGRAM ENHANCEMENT OPPORTUNITIES

Discharge Avoidance

This category focuses on means of improving detection of system weakness and responding to maintenance or operational needs prior to infrastructure failures.

Inspection and Lining

The Cities continue to perform regular video pipeline monitoring of gravity sewer lines. Although there are presently no guidelines for inspection of force mains, the Cities will continue to explore avenues to televise the Buena Vista force main and other DIP force mains.

The City of Carlsbad is studying the feasibility of using emerging technology to conduct a condition assessment of force mains. Sonar Solutions, a company that uses a sonar device within the pipeline to determine wall thicknesses, also conducted a site visit. The company was unable to conduct a condition assessment of the Buena Vista force main due to pipe bend angle constraints. ULC Robotics is another company whose technology is being explored. They use a remote-controlled and untethered crawling robot for condition assessments of natural gas mains; the company is beginning to transition to sewer and water infrastructure inspections, and inspection results look promising for pipelines with offsets and bends such as those on the Buena Vista line. The evaluation of additional new technologies, as they become known, is ongoing at this time. The City of Vista has had discussions with Downstream Services, Inc., a similar firm that may be able to perform a video and sonar profiling of the pipeline. Preliminary indications are that this option may not be feasible, even though the pipeline does not have to be emptied, drained, and flushed, because the pipeline will have to be 100% bypassed during the survey. Also, this technology may only provide a view of the interior lining and a rough approximation of the cross section of the pipeline with a sonar image. It may not provide adequate quality information regarding external corrosion conditions.

In addition, the Cities had discussions with International Pipe Lining Technologies, a firm who specializes in polyester-fleece pipe lining technologies. The outcomes of those discussions confirmed that polyester-fleece pipe lining material appears to be an acceptable material for lining force mains. There are many restrictions on the use of the material, however, such as limited length of a single pull (1,000 to 1,300 feet), thus requiring construction of several access ways, and a severe restriction on manageable bend angles (no bend greater than 12.5 degrees). These angles are exceeded within the Buena Vista force main. In addition, the polyester-fleece pipe lining material has to be installed in a clean pipeline with no water in the pipeline. This would require a 100% bypass of the force main for the time needed to empty, drain, clean, and flush the pipeline; shore, dewater, excavate and construct several access ways; and remove and realign a significant portion of the pipeline to remove 90 and 45 degree bends and line the pipeline.

The City of Vista is nearing completion (September 2007) of its Sewer Master Plan Update 2007. Vista’s Sewer Master Plan Update was done by an engineering consulting firm who specializes in infrastructure condition and risk assessment of force and gravity mains in the City. The Vista Sewer Master Plan Update will be an essential element to evaluate performance, planning, and design of force and gravity mains. Factors to be considered will be pipeline age, pipeline material, operation conditions, and soil, as well as other factors and parameters that would extend or reduce the probable service life of infrastructure or play a major role in shaping inspection and replacement decisions for Vista’s pipelines. The environmental, human health, and economic consequences and likelihood of pipeline failure will be further factors that could also influence further investigations such as a condition assessment of select pipelines. Similarly, the City of Carlsbad is in the process of identifying all sewer force mains that have a potential for premature failure similar to the sewer line along Buena Vista Lagoon. Based on the findings of the assessment, appropriate actions will be taken.

Pipeline Replacement

Based on many of the inspection avenues and lining options being infeasible or technologically challenged in an active facility, the Dischargers have pursued, and are in the process of, receiving governing body approvals that appropriate funds to begin engineering design of a parallel pipeline along an expedited timeline. This approval has gone further than accelerating scheduled pipeline replacement, but also has included lining of the existing pipe once the new pipe is in service. This would allow for insurance against future failures, but more importantly, it would provide redundant facilities to handle bypass needs in the event of a failure on either of the pipes. This is seen as a major benefit both in facilitating discharge avoidance and improving spill response and impact reduction.

Leak Detection

This category of potential actions addresses potential means to enhance detection of discharges. Within the Encina Wastewater Authority service area, wastewater flows are monitored by ADS, Inc. with flow meters and flow measurement devices at 16 metered locations. These meters are employed in the billing of member agencies of the JPA. With the present availability of system upgrades that would provide real time access to flow information, the Cities, as well as the other member agencies in the Encina Wastewater Authority, are pursuing the implementation of such upgrades through the EWA contract with ADS, Inc.

It was confirmed that additional sensors could be installed as an alternative system that would improve leak detection through use of system pressure and flow variance. The Dischargers have committed to installing automated alarm systems for potential leaks in this and other force main systems within their individual and collective operations areas. EWA has completed the installation of pressure and flow variance sensors at Buena Vista and Raceway Pump Stations. Real-time alarms, however, still rely on flow or pressure differential ranges. As such, small leaks or early ruptures may still go undetected, while larger ruptures should be detected earlier. The City of Carlsbad has met with ADS, Inc. to discuss the feasibility of a system that would provide real time flow tracking information. Carlsbad has coordinated with EWA to implement the system upgrades in the coming months.

Along these same lines, the City of Carlsbad has initiated discussions with Flow Metrix, a company that employs fixed-base leak detection devices in pressurized pipe. The technology is used presently on pressurized water pipelines. The City of Carlsbad, however, is still exploring its alternative use on pressurized sewer pipelines. In addition, the City of Carlsbad has had several meetings with Smartcover to discuss implementing flow change alarms on the Buena Vista force main. This would be a new use of the Smartcover technology.

As part of the City of Vista's Sewer Master Plan Update 2007, there will be a recommendation to monitor flows in the gravity flow sections of all major interceptor and trunk sewers in Vista. This process of monitoring will be reviewed to determine whether it offers a practical solution to more permanent monitoring of gravity sewers for potential capacity exceedence overflow events. Vista will also looking at the potential opportunities to install level alarms on gravity lines for potential overflow events.

Response Time and Resources

The response time and effectiveness of the actions taken after leak detection were immediate and comprehensive. There were a few points, however, where improvement could occur. To address these issues, the following measures are being undertaken:

- The City of Vista is currently scanning all of its improvement plans into a plan archival system with a central repository and indexing process that will allow more rapid access to data on trunk and main sewers, bypass interconnects, lift stations, and other critical infrastructure. In addition, the City of Vista's archival system will be accessible through the City's web page. The City of Carlsbad has previously scanned all sewer-related improvement plans into its Document Management System. Carlsbad is currently working on improving the plan indexing and retrieval process and providing a link between the Document Management System and the Geographical Information System. When completed, these integrated systems will facilitate the retrieval of all pertinent system information on field-deployed laptop computers, providing real-time access to critical data during emergency events.

- As part of the August 8, 2007, Buena Vista Pump Station Force Main Failure Joint Debriefing meeting hosted by EWA, it was agreed by the EWA member agencies that the members will upgrade call lists and create a general inventory of all assets that may be called upon in the case of emergencies. EWA will investigate possible formal agreements, like a Memorandum of Understanding, that can be set up and maintained by all member agencies and possible neighboring agencies for emergency response coordination.

- Asset inventories across mutual assistance agencies do not exist for emergency response coordination, and the requisition process to collect needed equipment can be hampered by calls to agencies or departments that lack needed resources. While it may be impractical to maintain a full list of resources, the Cities will upgrade call lists and create a general inventory of assets that may be called upon in the case of emergencies.

- To further resource readiness, the City of Carlsbad Public Works staff requested and received Council approval for: 2 new vactors, 1 new bypass trailer, 1 new CCTV van, replacement of 2 ½-ton pickups for use with the vactors, 1 new compact pickup truck, replacement of one 1-ton pickup for working on the lift stations, and adding 1 Public Works Supervisor, 4 Maintenance workers, and 1 Office Specialist for the collections system. Some or all of the proposed positions may be staffed by outside contracts. Vactors and pickup trucks will be used for line cleaning and maintenance on the lift stations, the CCTV van will be used to video inspect the gravity sewer pipelines, and the bypass trailer will be used to bypass sewer lines under construction repair or when inoperable due to blockages.

- The City of Vista Public Works Department continues to be well staffed with 18 active personnel for sewer maintenance. Currently, the City of Vista daily staffs and operates 1 CCTV van, 3 vactors, 1 rodding truck, dump truck, sewer service truck, heavy construction flat bed crane truck for spot pipeline repairs and manhole repairs and several miscellaneous pieces of equipment necessary for the care and maintenance of the City's sewer systems. In FY 07-08 Council approved budget, the Department will receive the following equipment replacements in its budget request: 1 vactor, 1 dump truck, and a flatbed crane truck. In addition, a new easement crawler hose cart machine was approved by the City Council. In FY 08-09, the Department has requested a replacement of 1 vactor.

Impact Minimization and Recovery

While each spill scenario encountered may have somewhat differing needs, almost any sizable spill into an inland lake, pond, or coastal lagoon will benefit from immediate and effective aeration.

As part of the Buena Vista Pump Station Force Main Failure Joint Debriefing meeting, it was also agreed that the Cities will update their respective Sanitary Sewer Overflow Response Plans during FY 07-08, including adding an element addressing incident response and damage minimization guidelines for various ecologically sensitive areas potentially affected by spills from the existing systems. In addition, EWA agreed to host internet links on their web page from its member agencies for each of their respective Sanitary Sewer Overflow Response Plans for universal access. The City of Vista will have its revised Sanitary Sewer Overflow Response Plan in place by September 2007, with specific provisions for a parallel environmental response independent of response crew activities. The City of Carlsbad is making revisions to its current Sanitary Sewer Management Plan (SSMP) based on the lessons learned from the Buena Vista Lagoon experience. In addition, Carlsbad will be performing a comprehensive overhaul of its SSMP in compliance with the State's Waste Discharge Requirements. The Response Plans of both Cities will be coordinated to ensure that common facilities, such as the Buena Vista Force main, are properly addressed.

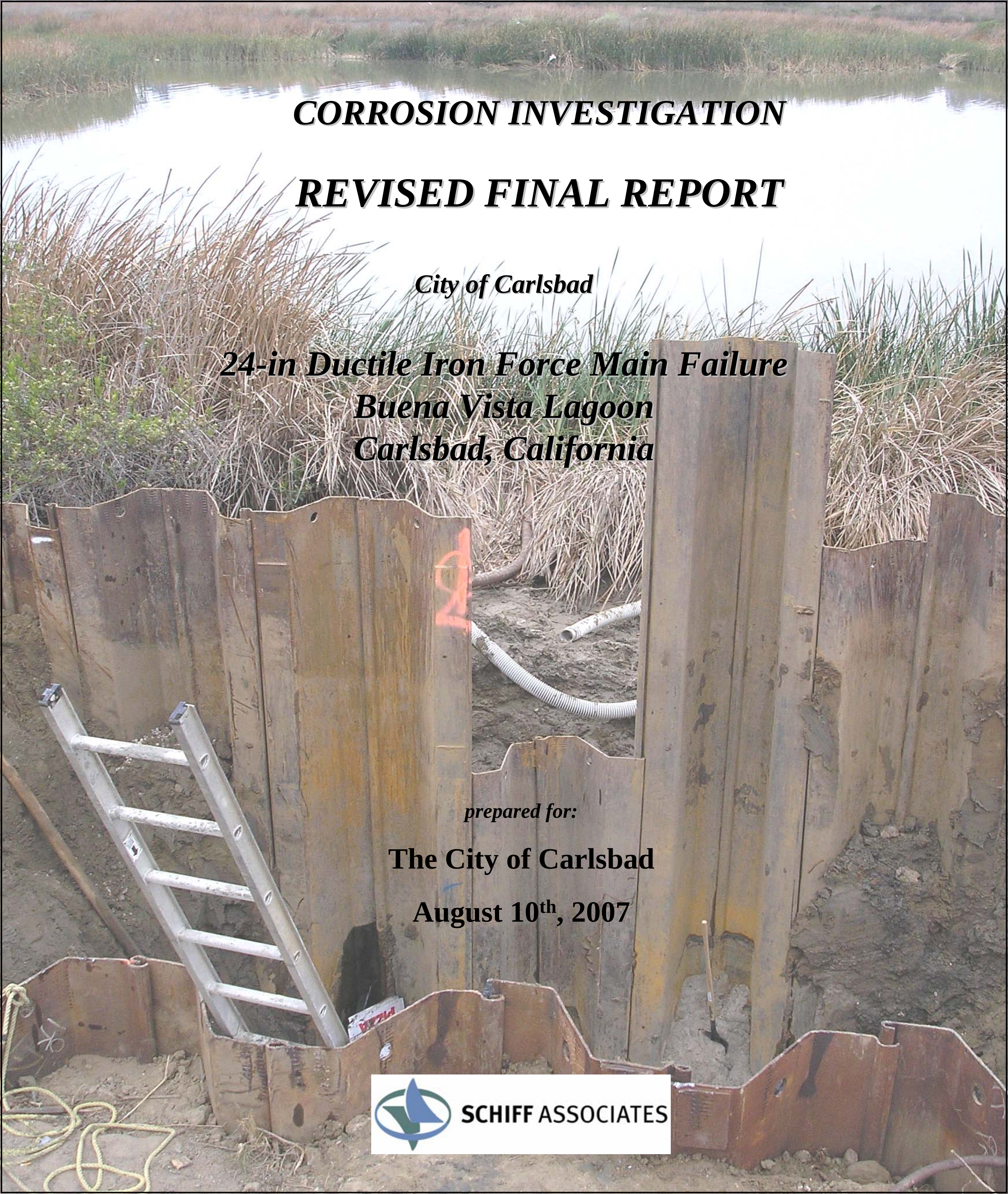
There was also an agreement made at the Buena Vista Pump Station Force Main Failure Joint Debriefing meeting to identify aeration equipment needs and options and stage that equipment at EWA for immediate availability for future events. This will allow an environmental response to be initiated immediately and independent of repair response crew activities.

Again, we continue to be very interested and available to sit down and meet with you and other staff members as soon as possible regarding the Buena Vista spill. The costs of spill response, the cost of early pipeline replacement, and the potential cost of penalties for the spill constitute a substantial fiscal impact on the Cities, particularly the City of Vista that will bear approximately 90% of the overall cost. Uncertainty in the penalties is of concern with respect to bond rating and financing capacity for present and future public projects. For this reason, it would be of great benefit for the Cities to move towards resolution of this matter in an expeditious manner.

Sincerely,

Keith W. Merkel
Principal Consultant
On behalf of the Cities of Vista and Carlsbad

cc: Rita Geldert (City Manager, City of Vista)
Glenn Pruim (Public Works Director, City of Carlsbad)



CORROSION INVESTIGATION

REVISED FINAL REPORT

City of Carlsbad

24-in Ductile Iron Force Main Failure Buena Vista Lagoon Carlsbad, California

prepared for:

The City of Carlsbad

August 10th, 2007

SCHIFF ASSOCIATES

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CORROSION INVESTIGATION
REVISED FINAL REPORT

CITY OF CARLSBAD
24-INCH DUCTILE IRON FORCE MAIN FAILURE
BUENA VISTA LAGOON
Carlsbad, California
NCRU: 01-0743.02 & 01-764.02:ebecker

Prepared for

The City of Carlsbad
1635 Faraday Avenue
Carlsbad, California 92008

SA #07-0477ENG

August 10, 2007

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EXECUTIVE SUMMARY

A sewer force main (FM) jointly owned and operated by the City of Carlsbad and the City of Vista was reported to be discharging sewage into the Buena Vista Lagoon on April 1, 2007. Schiff Associates (SA) was contacted by the City of Carlsbad on the morning of April 3, 2007. Dr. Graham Bell, PE of SA visited the leak site, inspected the pipe and excavation, obtained soil samples and visually inspected the exposed pipe that same morning and early afternoon.

The ductile iron pipe (DIP) segment of the raw sewage force main alignment begins at the Buena Vista Lift Station and runs generally southwest. The discharge occurred about 700 feet downstream (west) of the Buena Vista Lift Station, on a 24-inch diameter DIP installed in 1982 and operating at or below 40-psi. Corrosion control for the exterior consisted of 8-mil polyethylene encasement (PE) per AWWA C105, and cement-mortar lining inside the pipe. The restrained pipe joint excavated was not intentionally bonded for electrical continuity by means of an external bonding strap. In the area of the excavation, gravel had been used to back fill the pipe in the pipe zone, probably due to groundwater encountered during installation.

A 40-inch long section of the FM was removed and replaced. The removed section of pipe included the leak and a restrained joint immediately upstream of the leak location. The sewage discharge was through a rectangular hole of approximately 21.7 inches^2 in the pipe just below spring line (reported as 4:30 clock position when facing downstream) on the lagoon (west) side of the pipe approximately 15 inches from the restrained joint. The hole exhibited characteristics consistent with external corrosion (concave edges on the exterior). The exterior of the pipe exhibited corrosion from sewage which leaked out and was trapped against the pipe by the PE The inside surface of the pipe was uniformly in good condition and internal corrosion was not the source of the corrosion hole.

An unknown underground irrigation pipeline was discovered approximately 4-feet above the force main during excavation and repair work on the force main. The 3-inch diameter irrigation line was unusually deep, and there was no record of the pipeline. The irrigation line was previously repaired, suggested by a section of the line containing compression couplings at each end. It is unlikely that the leak in this line damaged the liner. Also, in the absence of inspection records, specifications, or any other records, it was unlikely that there was a requirement for over excavation and re-compaction especially to 4-feet below the pipe.

Evidence of external corrosion damage due to leaked sewage near a restrained joint made it necessary to investigate the integrity of the restrained joint seal. The restrained joint, flange and seals were carefully sectioned to inspect for evidence of joint and gasket leakage. No evidence of leakage was found in any area of the joint or gasket.

Fractographic, metallographic, chemical analysis and testing for mechanical properties were conducted on specimens from the pipe sample. The pipe material was tested for tensile strength and Charpy impact values in accordance with AWWA C151/A21.5-81. The results of the mechanical testing showed that the pipe material did not meet the requirements for ductile iron

pipe. The nonconforming impact properties of the material did not cause the corrosion, nor did they have any appreciable effect on the corrosion resistance of the pipe. The microstructure showed that portions of the pipe were closer to that of grey cast iron. This appears to have been a manufacturing issue, but we do not believe that this contributed to the leak since grey and ductile iron have very similar chemical composition and the same general corrosion resistance.

Soil samples collected from the excavation were tested for electrical and chemical properties to determine corrosivity towards DIP. Resistivity and soil chemistry characteristics (high chloride concentration) along with the presence of sulfides and negative redox potentials (indicating anaerobic condition consistent with microbiological corrosion activity) result in extremely corrosive soils for DIP. Using the DIPRA 10-point Soil Test Evaluation from Appendix A of AWWA C105-82, these soils score 20.5 out of a possible 25.5 points. A score of 10 or higher classifies the soil as corrosive to DIP and protection against exterior corrosion should be provided. External corrosion protection recommended per AWWA C105-82 was polyethylene encasement as was installed. PE was the industry standard for corrosion protection at the time of design and construction.

Linear polarization resistance (LPR) tests using steel surrogate electrodes were performed in order to estimate the corrosion rate on exposed iron. Results of the LPR tests indicate general corrosion rates on the order of 8 to 10 mils per year (0.008 to 0.010 inches per year) and a tendency toward pitting which could accelerate time to perforation.

The failed pipe section did not show degradation of the cement-mortar lining, indicating there are no air pockets where sulfuric acid can form and rapidly degrade the lining resulting in corrosion of the crown of the interior of the pipeline. Based on all of the information available, the most probable cause of the corrosion hole was external corrosion of the pipe at a hole in the PE encasement which most likely occurred during construction. The exposed exterior iron surface corroded over a period of time, measured in years, down to the cement mortar liner. The exposed area of the liner continued to grow in size as the supporting iron receded and sewage fluids from inside the pipe permeated through the cement mortar. The permeated sewage fluids were trapped by the polyethylene encasement. The permeated and trapped sewage fluids increase the exterior corrosion rate and subsequent damage on the lower half of the pipe. Soil pressure on the polyethylene encasement or tape around the pipe used to keep the polyethylene encasement in place tended to prevent the severe corrosion further along the pipe and above the spring line. The major volume of sewage was discharged when the membrane of cement mortar liner, corrosion product and supporting fill could not contain the pressure or was dislodged due to a mechanical event.

If this pipe is to remain in operation, it should be lined with HDPE or CIPP or cathodically protected. Cathodic protection would require bonding all pipe joints for electrical continuity. Joint bonding would consist of thermite brazing two or three cables to pipe on each side of a joint. Cathodic protection will halt further external corrosion but will not prevent an imminent failure of pipe that has suffered similar significant corrosion damage. Bonding pipe joints should include inspection of the pipe at every excavation. Value engineering analysis can be conducted to determine the economic viability of excavation for joint bonding and subsequent cathodic protection versus installing another pipe or lining then existing pipe.

The pipe could be replaced. The results of the soil analysis show that DIP would require protection beyond PE encasement in accordance with the most current version of AWWA C-105. Alternatives for DIP are High Density Polyethylene (HDPE) or Cured In Place Plastic (CIPP) liner are also options for repair and replacement but valving and other operational and construction issues must be considered.

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FINAL REPORT

CORROSION INVESTIGATION

City of Carlsbad
24-in Force Main Failure
Buena Vista Lagoon

SA Project # 07-0477ENG
NCRU: 01-0743.02 & 01-764.02:ebecker
August 10, 2007

To: Bill Plummer, P.E.
City of Carlsbad Project Manager

From: Graham E.C. Bell, Ph.D., P.E.
Project Manager

Prepared By: Schiff Associates

Graham E.C. Bell, Ph.D., P.E.

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1. INTRODUCTION AND BACKGROUND

A sewer force main jointly owned and operated by the City of Carlsbad and the City of Vista was discharging sewage into the Buena Vista Lagoon on April 1, 2007. Schiff Associates was contacted by the City of Carlsbad on the morning of April 3, 2007 to inspect the site and investigate the failure. This final report details both the investigative work and our conclusions.

1.1. DESCRIPTION OF THE FORCE MAIN PIPELINE

The ductile iron portion of the force main alignment begins at the Buena Vista Lift Station located on Marron Road, north of Jefferson Street. The raw sewage force main runs generally southwest from the Buena Vista Lift Station crossing near the lagoon in the Marron Road bridge deck and runs in Jefferson Street to transition to asbestos cement pipe force main that was installed by Caltrans to cross Interstate 5 (I-5). This portion of the force main alignment contains a parallel asbestos-cement pipe (ACP), 16-inch diameter. The ACP parallel begins at a wye with a plug valve installed in the DIP reach just past the point of the break. Flow can be directed in the ACP or DIP by operating a plug valve. East of I-5 there is another wye and plug valve. Crossing under I-5 are parallel ACP barrels, and the DIP connects to one barrel with the parallel ACP connecting to the other barrel under I-5. An aerial view of the alignment is included with the appendices. The leak occurred about 700 feet downstream (west) of the Buena Vista Lift Station.

The force main is 24-inch diameter ductile iron pipe (DIP), and was installed circa 1982. Corrosion control for the exterior consisted of 8-mil thick clear, most likely linear low density, polyethylene encasement (PE) per American Water Works Association (AWWA) C105-82. The interior was lined with cement-mortar per AWWA C104. The pipe wall thickness was approximately 0.41-inch (Thickness Class 51) with restrained joints. The pipe in the vicinity of the leak operated at a pressure at or below 40-psi. The restrained pipe joint excavated was not intentionally bonded for electrical continuity by means of an external bonding strap. In the area of the excavation, gravel had been used to back fill the pipe in the pipe zone, probably due to groundwater encountered during installation.

1.2. SCOPE OF WORK

On 3 April 2007, Dr Graham Bell visited the site for inspection, documentation, photography and sample removal. He performed the following:

- Collected soil and gravel samples from the repair excavation at the discharge site
- Collected a sample of the polyethylene encasement from the west end of the excavation
- Observed the repairs to the pipe
- Examined and documented the as-excavated condition and external corrosion on the section of pipe removed

In addition, Dr. Bell met with representatives from the City of Carlsbad and the City of Vista on April 12, 2007 at the Encina Wastewater Treatment Plant to receive documentation and discuss the investigation.

This final report presents test results and responds to Investigative Order No. R9-2007-0060 issued by the California Regional Water Quality Control Board, San Diego Region (Regional Board). Statewide Waste Discharge Requirements (WDRs) prohibit Sanitary Sewer Overflows (SSOs), or leaks that result with discharge of sewage into natural waters of the state and also prohibit discharge of raw sewage from the system upstream of a sewage treatment plant, which in this case would be the Encina Wastewater Treatment Plant. The Regional Board is calling for information that shows the actions by the municipalities to prevent sewage discharge, repair the failed pipe, and investigate water quality impacts from the sewage discharges.

2. PHYSICAL EXAMINATION OF PIPE SPECIMEN

2.1. OBSERVATIONS

A 40-inch long section of the leaking pipe was removed by the Contractor at the excavation site. The 40-in long pipe was sectioned into two pieces along the plane of the springline to facilitate removal and included a restrained joint. The sewage discharge was due to an approximate 3-in x 12-in rectangular hole in the pipe just below the spring line (reported as 4:30 clock position when facing downstream) on the lagoon (west) side of the pipe, approximately 15 inches from the restrained joint.

An unknown underground irrigation pipeline was discovered approximately 4-feet above the force main during excavation and repair work on the force main. The 3-inch diameter irrigation line was unusually deep, and there was no record of the pipeline. The irrigation line was previously repaired, suggested by a section of the line containing compression couplings at each end. It is unlikely that the leak in this line damaged the liner. Also, in the absence of inspection records, specifications, or any other records, it was unlikely that there was a requirement for over excavation and re-compaction especially to 4-feet below the pipe.

Two soil samples were collected at the excavation site; one from the pipe trench and one from the wall of the excavation adjacent to the failure. A sample of gravel from next to the pipe was collected, and a sample of the polyethylene encasement was obtained. The polyethylene sample was transmitted to the Ductile Iron Pipe Research Association (DIPRA) to be analyzed for material conformance with American Water Works Standard C105.

The rectangular corrosion hole was preserved in one half of the sectioned pipe. Two in-line pipe couplings and a short section of pipe were installed in order to place the force main back in service (see Figure 1). The two sections of pipe including the intact restrained joint were preserved and transported to Encina Wastewater Treatment Plant, 6200 Avenida Encinas, Carlsbad, CA. From there they were moved to Schiff Associates, 431 W. Baseline Rd, Claremont, CA 91711 for cleaning, observation and analysis. The sections are currently stored in Claremont.

Figure 1 - Excavation Site

After transportation to Claremont, the pipe sections were cleaned with 2600 psi potable water pressure washer to reveal the extent of corrosion under corrosion products, surface debris and graphitization. The hole in the pipe exhibited characteristics consistent with external corrosion (concave edges on the exterior). The inside surface of the pipe was uniformly in good condition and internal corrosion was not the source of the corrosion hole.

The hole was photographed upon removal of the excavation, at the Encina WTP maintenance area and after transportation to Schiff Associates office. A CAD program was used on photographs of the hole to determine both the area of leakage and the perimeter of the hole. The results showed that area of the hole to be 21.7 in^2. The perimeter of the hole is 28.36 inches in length. This is accurate to 13% or approximately ± 2.8 inches.

Figures 2 to 6 below present photographs of the observations and findings.

Figure 2 – Sectioned pipe with failure (below springline)

This is the condition of the pipe section, from below the springline, at the failure site. The leakage hole is in this section, red arrows.

Figure 3 – Sectioned pipe opposite side of failure (above springline)

This is the section from above the spring line. This has not been cleaned, yet the band on the pipe adjacent to the bell can be seen. It is this band that delineates the taping of the PE encasement. There is no appreciable corrosion outside the encasement or above the springline. The four red arrows locate the area of the corroded band.

Figure 4 - Corrosion hole close-up

The stipple pattern from the foundry mold is still present. One characteristic of graphitic corrosion is that small details like this may still be seen but the iron has been removed due to corrosion. In this photo the stipple pattern has been retained on the corrosion product. The red arrows show the thickness of the cement liner. There is no metal left, corrosion has removed the supporting iron. The liner failed in a fast manner and not from a slow dissolution. There is no indication that the line had been thinned from a long period of time of leakage. This supports the conclusion that the leak was not slow with the hole gradually growing in size.

This is the pressure cleaned upper section. The heavily corroded area is the lower portion of the Figure. This is showing the area adjacent to the taped PE encasement. After the pipe was shot blasted, it was discovered that the liner was the only material left in some of these areas, the iron was gone due to corrosion. The marked area in the upper right locates where material was taken for the mechanical tests (Charpy impact bars, metallography and chemical analysis). A similar sample was taken 180° from this on the lower section. Figures 9 through 12 are from these locations.

Figure 5 - Cleaned upper section of pipe

Figure 6 – Four photos showing asphaltic coating and joint condition

Three photos from Figure 6 above show the excellent condition of the asphaltic lining applied at the foundry and sealed by the gasket. The pristine condition of these pipe surfaces is certain evidence that there was no leaking at the compressed joint. The lower right photograph in Figure 6 is a section through the gasket material showing a good pipe joint. The inspection of the gasket's surface after removal of the flange showed the gasket material to be undamaged, consistent with a leak free joint.

2.2. METALLOGRAPHY

Heat treatment is important in ductile iron forming good mechanical properties; therefore the use of the optical metallography is key in verifying proper heat treatment by studying the microstructure. Understanding the microstructure will tell the heat treating and casting history of the ductile iron.

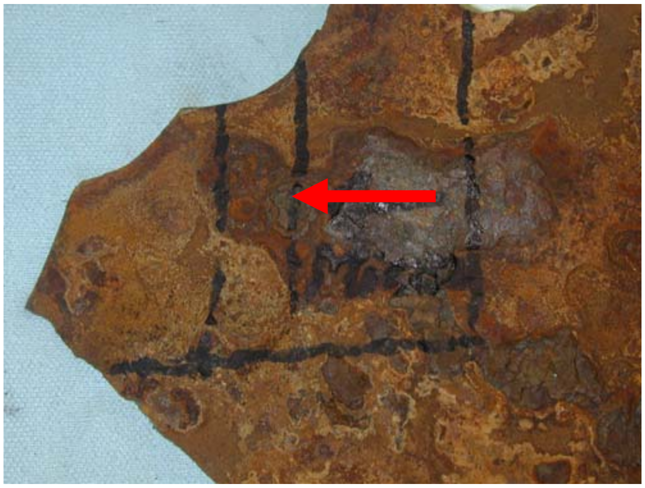


Figure 7 – Pipe specimen identified for metallographic analysis

Figure 8 – Close up of corrosion product

Besides the metallographic examination taken from the area in Figure 5 another sample was taken from the bottom of a graphitic corrosion pit as seen in Figures 7 and 8. The red arrows locate the plane of sectioning through the remaining metal and the corrosion product.

Figure 8 is a close-up of the plane (red arrow) of sectioning through the corrosion product and the DIP base metal. The results of the metallography are shown in micrograph, Figure 13. The micrograph also shows the structure of the DIP to be vermicular as the inside diameter is approached. The same structure as seen in Figure 11.

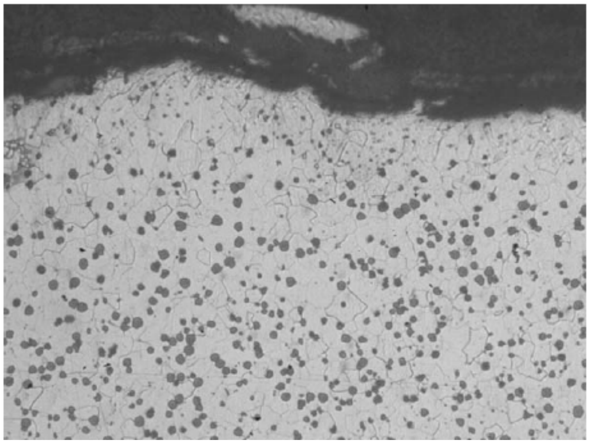


Figure 9 - Light micrograph of pipe surface

Micrograph of outside diameter surface
Upper specimen
Etched 2% Nital
Magnification 200X
Cast Ductile Iron

The microstructure is typical of that for ductile iron. The graphite nodules are dispersed. This is an acceptable microstructure. It is meets the ASTM A247 Type I and Type II chart. It is of interest that this shows no corrosion or loss of metal on the outside surface of the pipe in this specific area.

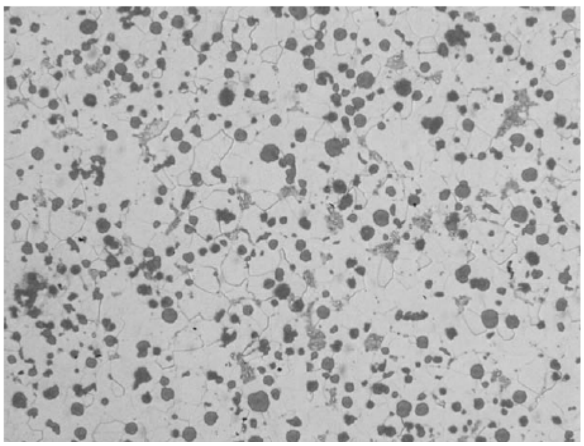


Figure 10 - Light micrograph of pipe core

Micrograph of core
Upper specimen
Etched 2% Nital
Magnification 200X
Cast Ductile Iron

This shows the microstructure of the mid section of the wall of the ductile iron. Some of the graphite nodules are well shaped and some are showing an irregular, non preferred shape. The microstructure is starting to decay and exhibit the structure of that found in grey iron. It is meets the ASTM A247 Type II chart.

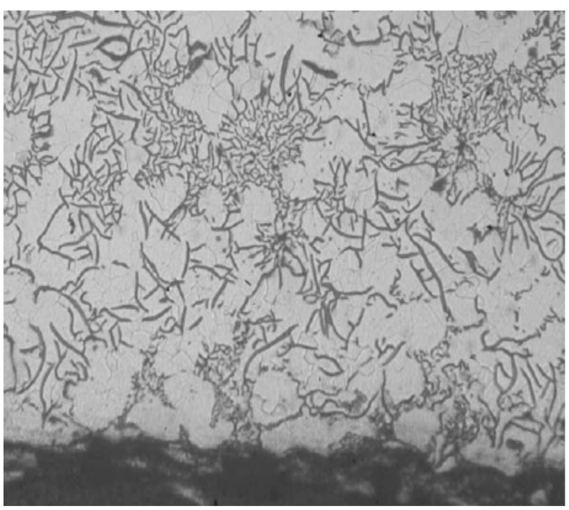
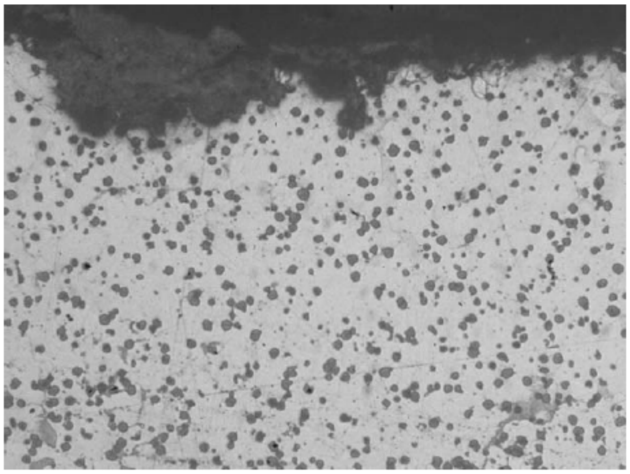


Figure 11 - Light micrograph of pipe interior

Micrograph of inside diameter surface
Upper specimen
Etched 2% Nital
Magnification 200X
Cast Ductile Iron

The microstructure is not ductile iron. Because of the cooling rate difference between the inside surface and the outside there is a difference in the microstructure. There are no graphite nodules in the microstructure. This is not an acceptable microstructure. It meets the ASTM A247 Type V II Chart. The cement liner was protecting this surface from corrosion. The corrosion rate would be similar between the nodular graphite and this vermicular structure.

The micrographs of the specimen taken at 180°, Lower Specimen (Figure 12), are similar to the previous micrographs, Figures 9, 10, 11). The outside diameter surface does show more corrosion than this one. This is consistent with the cause of corrosion failure presented in this report. The specimen from the lower section is below the springline and would see some more metal loss then the upper section.



Micrograph of outside diameter surface
Lower specimen.
Etched 2% Nital
Magnification 200X
Cast Ductile Iron

The microstructure is typical of that for ductile iron. The graphite nodules are well shaped and evenly dispersed. This is an acceptable microstructure. It is meets the ASTM A247 Type I. chart. Because this was taken from the lowest outer section of the DIP it does evidence slightly more corrosion.

Figure 12 - Light micrograph of pipe surface (below springline)

Figure 13 is the microstructure of the iron located below the corrosion pit, (Figure 8). The pit is due to graphitic corrosion.

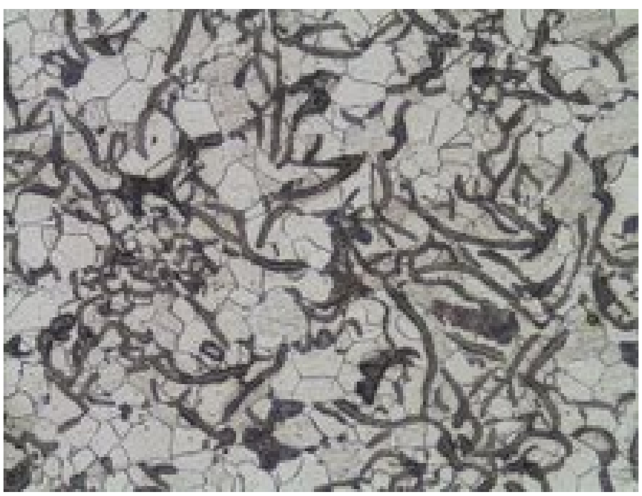


Figure 13 - Light micrograph of structure below the graphitization pit.

Micrograph of DIP below corrosion pit.
Corrosion specimen.
Etched 2% Nital
Magnification 200X
Cast Ductile Iron

This is not ductile iron. It is the same vermicular structure as seen in Figure 12. There are no graphite nodules in the microstructure. This is not an acceptable microstructure for impact resistance. The microstructure has no susceptibility or resistance to corrosion over that of a nodular structure. The cement liner was protecting this structure from corrosion from the inside of the pipe. The corrosion came from the outside diameter thought the nodular structure. The corrosion rate would be similar between the nodular graphite and this vermicular structure.

DISCUSSION OF GRAPHITIC CORROSION

The corrosion engineering industry uses the term "graphitic corrosion" to describe how in conductive environments there is a selective loss of the iron matrix in order to galvanically protect the graphite phase in the metal. Both ductile iron and grey cast iron will suffer from graphitic corrosion. The use of terms such as degraphitization and graphitization corrosion are non-standard terms when used to describe types of cast iron.

As previously discussed the corrosion rates of DIP and grey iron pipe may be similar in some environments. In evaluating the condition of the grey iron grub screws it is clear that they have undergone severe corrosion. One may conclude that the grey iron is more susceptible to corrosion and thereby extrapolate that the close-to-grey iron structure in the DIP will evidence more corrosion. On the other hand the extent of corrosion to the DIP in the area of the bell, below the springline, is also severe. It is more logical to conclude that the corrosion of both was similar and that there was no real difference.

The key to understanding the issue of the grey iron having similar rates of corrosion is that the outside diameter did have the correct nodular structure and was subjected to a more severe environment as the inside vermicular structure was protected by the cement liner. Only when the pit depths extended into the wall to such a depth that the vermicular structure was revealed and also attacked. It was the ductile structure that had to have been removed in order to expose the grey iron, vermicular graphite. There is not enough evidence one way or another in this corrosion investigation to classify the grey iron vermicular graphite as having inferior corrosion resistance to the expected nodular graphite.

Figure 14 – Corrosion of fasteners

Figure 14 above shows two sets of fasteners. The left is surface corroded grey iron. It is heavy and the fracture surface is clean and metallic in appearance. The pieces on the right are the same fasteners but they have undergone graphitic corrosion. They have very little weight because of the loss of the iron in the matrix

2.3. MECHANICAL PROPERTIES TESTING

Samples were taken at 180° at a distance of 40 inches from the bell of the pipe. Three impact bars and one tensile were taken from each location. The results are tabulated below and compared with the requirements of AWWA C151/A21.5-81, Ductile-Iron Pipe, Centrifugally

Cast in Metal Molds or Sand-Lined Molds, for Water or Other Liquids. The Charpy values, tensile strength and % elongation do not meet the minimum required.

TEST	Charpy ft-lbs (average of 3)	Tensile Strength (psi)	Yield Strength (psi)	% Elongation
60-42-10	7 ft-lbs (minimum)	60,000 (minimum)	42,000 (minimum)	10% (minimum)
Sample upper	3.6	59,000	42,700	6.5
Sample lower	2.7	58,000	42,200	5.0

Table 1 – Mechanical Testing to AWWA C151/A21.5-81

2.4. CHEMICAL TESTING

Because there were fasteners at the connection which were also corroding, a chemical analysis of all materials was conducted. The corrosion of the fasteners did not cause nor did they influence the corrosion. This testing was done to confirm the material and for information purposes. There was some discussion that the fasteners were "Corten", a copper alloyed steel, good for general weathering. Neither the nut nor the bolt was "Corten". This is not a problem since "Corten" would not be a good selection for buried fasteners.

The AWWA C151/A21.5-81, Ductile-Iron Pipe, Centrifugally Cast in Metal Molds or Sand-Lined Molds, for Water or Other Liquids standard is silent regarding the chemical composition of the DIP. This is reasonable as the Charpy, mechanical testing and the required hydrostatic test are good methods for control of the strength of the pipe. The composition is not a critical factor as the properties are ultimately dependent on the cooling rate and subsequent heat treating of the pipe.

Table 2 below presents the chemical composition results for the pipe, a cast-iron grub screw and the steel nut and bolt for the flange connection. Note that the composition of the grey cast iron is similar to that of the ductile.

Element	DIP Upper	DIP LOWER	DIP PITT	Grey Iron	Steel Nut	Steel Bolt
C	3.29	3.32	3.18	3.86	0.16	0.10
Mn	0.34	0.34	0.33	0.35	O.77	0.40
Si	2.74	2.74	2.53	2.71	0.26	0.44
P	0.024	0.025	0.013	0.027	0.07	0.11
S	0.011	0.010	0.01	0.014	0.016	0.014
Cr	0.13	0.13	0.13	0.06	0.85	0.83
Ni	0.069	0.072	0.08	0.05	0.49	0.25
Cu	0.193	0.190	0.180	0.06	0.30	0.35
Mg	0.014	0.014	NOT REPORTED	NOT REPORTED	NOT REPORTED	NOT REPORTED
Al	0.012	0.012	NOT REPORTED	NOT REPORTED	NOT REPORTED	NOT REPORTED
Mo	0.013	0.015	0.015	0.01	>0.01	0.03
Iron	BALANCE	BALANCE	BALANCE	BALANCE	BALANCE	BALANCE

Table 2 - Chemical Analysis of Ductile Pipe, Grey Iron and Fasteners

3. POLYETHYLENE ENCASEMENT

The use of the PE in corrosion protection of DIP is not intended to keep all moisture and corrosives away from the iron surface, as discussed previously. Instead, its purpose is to control and mitigate the replenishment of the corrosive with oxygen which further corrodes the iron. Compaction and settling tends to seal the PE and the rate of corrosion should decrease or even stop. Present day DIPRA procedures call for use of corrosion control measures beyond just the use of PE in highly corrosive soils; this was not the case when the DIP line was installed.

A sample of the polyethylene encasement was transmitted to DIPRA, and found to be in conformance with American Water Works Standard C-105.

4. LABORATORY TESTING OF SOILS

Laboratory testing of soil can provide insight to some of the corrosion mechanisms. The soil's electrical resistivity, a measurement of the soil's resistance to conduct electricity or corrosion current, is an important factor in determining the soil's corrosiveness toward buried metallic structures, particularly ferrous metals. Corrosion of buried metals is an electrochemical process in which the amount of metal loss is directly proportional to the flow of electrical current (DC) into the soil. Corrosion currents, following Ohm's Law, are inversely proportional to soil resistivity. Low electrical resistivity soil is associated with high chemical and moisture content, and usually indicates a corrosive soil.

A correlation between electrical resistivity and corrosivity toward ferrous metals is:

Soil Resistivity in ohm-centimeters			Corrosivity Category
over		10,000	mildly corrosive
2,000	to	10,000	moderately corrosive
1,000	to	2,000	corrosive
below		1,000	severely corrosive

Other soil characteristics that may influence corrosivity toward metals are pH, chemical content, soil types, aeration, anaerobic conditions, and site drainage.

4.1. TEST PROCEDURES

The electrical resistivity of the soil samples collected at the excavation site, one from the pipe trench and one from the wall of the excavation adjacent to the failure, were measured in a soil box per ASTM G57 in their as-received condition and again after saturation with distilled water. Resistivity is at about its lowest value when the soil is saturated. The pH of the saturated samples was measured. A 5:1 water: soil extract from each sample was chemically analyzed for the major soluble salts commonly found in soil. Test results are shown in Table 1 in Appendix B.

4.2. TEST RESULTS

The electrical resistivities of both soil samples and the gravel were in the severely corrosive category with as-received moisture and after saturation. The gravel and soil pH values ranged from 7.4 to 8.3. This range is mildly alkaline to strongly alkaline. The chemical content of the samples was very high with chloride, particularly corrosive to ferrous metals, and sulfate as the predominant constituents.

The positive reactions for sulfide and the negative redox potentials indicate reducing conditions in which anaerobic bacteria are active. Bacteria maybe due to the lagoon environment or leaked sewage.

This soil is classified as severely corrosive to ferrous metals. Using the DIPRA 10-point Soil Test Evaluation from Appendix A of AWWA C105-82, these soils score 20.5 out of a possible 25.5 points. A score of 10 or higher classifies the soil as corrosive to DIP and protection against exterior corrosion should be provided.

4.3. LINEAR POLARIZATION RESISTANCE AND ELECTROCHEMICAL IMBALANCE TESTING

Linear polarization resistance (LPR) testing was conducted to determine, by bench testing in the laboratory, the corrosion rate of ductile iron in these soils. LPR probes were made using steel electrodes as a surrogate for DIP. Electrodes were placed in the saturated soil samples taken from the excavations. The reported corrosion rates for the samples represent general corrosion rates for the electrode surface (5 cm^2). The measurement is derived from the average of the corrosion current shifts resulting from a 10 mV anodic polarization and a 10 mV cathodic polarization of the two electrodes. These DC measurements are compensated for solution resistance by an AC measurement (approximately 1 KHz).

Measurements of electrochemical imbalance between the two electrodes were also measured. The Imbalance values are shown in Imbalance Units. The scale factor is 0.5 microamperes per square centimeter of electrode surface which equates to 2.5 microamperes per imbalance unit (IU). This scale factor was determined from empirical data and selected so that when the corrosion rate in mils per year could be compared with the Imbalance reading in IU. This comparison is used as the basis for a qualitative interpretation with regard to the dominant corrosion mechanism. If corrosion rate > imbalance; this is an indication of general corrosion taking place. If corrosion rate < imbalance; this is an indication of localized corrosion activity (pitting). Since the imbalance reading is a "snapshot" of the ZRA measured current between the electrodes rather than continuous current, little can be said for the character of the localized corrosion. Also, since it is displayed as an absolute value, it is impossible to determine if localized corrosion is occurring on one or both electrodes.

The measurements taken from both of the soil samples, shown in Figure 15 indicate that both general corrosion and localized corrosion are taking place.

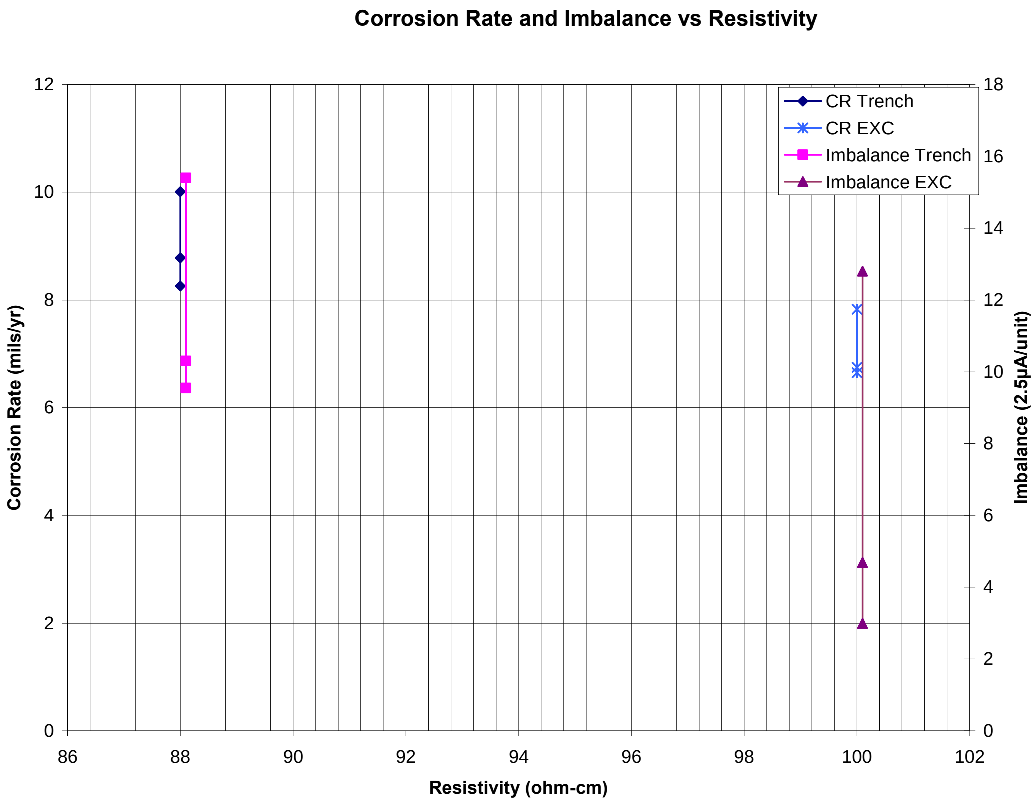


Figure 15 - LPR Tests and ECI for Soil Samples from Excavation

5. CORROSION CONTROL FOR DIP CIRCA 1982: AWWA C105-82

The American Water Works Association (AWWA) Standard C-105, Polyethylene Encasement for Ductile Iron Piping for Water and Other Liquids, 1982 version, was sent to us by Ms. Jennie Nevens of DIPRA. The Standard was preceded by The Cast Iron Pipe Research Association (CIPRA) work that demonstrated loose polyethylene encasement provides protection against soil corrosion and against stray current.

Polyethylene encasement was the state of the art for ductile iron pipe installations in corrosive environments in 1982. DIPRA and AWWA C105-82 did not recommend joint bonding and cathodic protection for ductile iron piping systems. DIPRA believed at that time and to some extent today that joint bonding could cause long line currents which may have negative effects on pipe corrosion. DIPRA relied on the polyethylene encasement to protect the pipe. This methodology was standard in the industry in the 1970s and 1980s. As infrastructure has become more developed, the cost to excavate an existing pipeline has increased, and the access to conduct dig-ups has decreased. An American Water Works Research Foundation study on External Corrosion of Distribution Systems in 2004 found that the greatest future cost to infrastructure is and would be the extent of electrically discontinuous piping underground. Cathodic protection can be used to extend the life of a metallic pipeline, yet it requires pipe joints to be electrically continuous.

The foreword of the 1982 AWWA C105 Standard states that the polyethylene encasement had maintained its integrity after 20-years of testing its exposure in severely corrosive soil. Since 1958, polyethylene encasement has been used extensively in the waterworks industry to protect cast and ductile iron pipe in corrosive environments and it is still in use today as a method of corrosion protection for DIP. The 1982 Standard calls for physical and dielectric requirements for the polyethylene, details installation methods, and has a system for rating soil corrosivity to determine if the encasement is necessary in Appendix A. Using the DIPRA 10-point Soil Test Evaluation from Appendix A of AWWA C105-82, these soils score 20.5 out of a possible 25.5 points. A score of 10 or higher classifies the soil as corrosive to DIP and protection against exterior corrosion should be provided. Exterior corrosion protection recommended by AWWA C105-82 is polyethylene encasement as was done for the subject force main.

A copy of AWWA C105-82 is contained in Appendix D.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

- The most probable cause of the corrosion hole was external corrosion of the pipe at a hole in the PE encasement which most likely occurred during construction. The exposed exterior iron surface corroded over a period of time, measured in years, down to the cement mortar liner. The exposed area of the liner continued to grow in size as the supporting iron receded and sewage fluids from inside the pipe permeated through the cement mortar. The permeated sewage fluids were trapped by the polyethylene encasement. The permeated and trapped sewage fluids increase the exterior corrosion rate and subsequent damage on the lower half of the pipe. Soil pressure on the polyethylene encasement or tape around the pipe used to keep the polyethylene encasement in place tended to prevent the severe corrosion further along the pipe and above the spring line. The major volume of sewage was discharged when the membrane of cement mortar liner, corrosion product and supporting fill could not contain the pressure or was dislodged due to a mechanical event.

- The discharge was at a single, elongated hole of approximately 21.7 $inches^2$ which was located at the 4:30 o'clock position (below the spring line) on the pipe.

- There were other externally corroded areas where only the cement liner was intact, yet without leakage. These were either below the spring line or under a band running along the entire circumference due to the taping or constriction of the PE by backfill.

- The failed pipe section did not show degradation of the cement-mortar lining, indicating there are no air pockets where sulfuric acid can form and rapidly degrade the lining resulting in corrosion of the crown of the interior of the pipeline.

- The tape or other backfill restraint of the PE tended to prevent the severe corrosion further up the pipe, especially above the spring line.

- The iron corroded over a period of time, measured in years, down to the liner. The exposed area of the liner continued to grow in size as the supporting iron receded. The sewage was discharged when the membrane of cement liner, corrosion product and supporting fill could not contain the pressure. It was at this recent time that the discharge occurred.

- The joint and flange were carefully sectioned to inspect for evidence of joint and gasket leakage. No evidence of leakage was found in any area of the joint or gasket. The original asphaltic coating from pipe production was found to be intact on the entire circumferential area of contact between the pipe and the gasket material.

- The microstructure showed that portions of the pipe were closer to that of grey cast iron, which is known to have the same general corrosion resistant to that of ductile iron.

- The pipe material was tested for tensile strength and for Charpy impact values in accordance with AWWA C151/A21.5-81. The results of the mechanical testing showed that the pipe material did not meet the requirements for Grade 60-42-10, ductile iron pipe. The nonconforming impact properties of the material did not cause the corrosion, nor did they have any appreciable effect on the corrosion resistance of the pipe.

6.2. RECOMMENDATIONS

- If this pipe is to remain in operation, it should be lined with HDPE or CIPP or cathodically protected. Cathodic protection would require bonding all pipe joints for electrical continuity. Joint bonding would consist of thermite brazing two or three cables to pipe on each side of a joint. Cathodic protection will halt further external corrosion but will not prevent an imminent failure of pipe that has suffered similar significant corrosion damage. Bonding pipe joints would should include inspection of the pipe at every excavation. Value engineering analysis can be conducted to determine the economic viability of excavation for joint bonding and subsequent cathodic protection versus installing another pipe or lining then existing pipe.

- The results of the soil analysis call for a DIP replacement pipeline to have additional corrosion control beyond PE encasement per AWWA C-105, Appendix A. DIP would require cathodic protection. A High Density Polyethylene (HDPE) or Cured In Place Plastic (CIPP) liner are also options for repair and replacement but valving and other operational and construction issues must be considered.

- The pipeline can have a quick evaluation of its electrical continuity by accessing the pipe at the valve nut at the transition to asbestos cement pipe at the I-5, and aboveground pipe in the bridge deck near the pump station end of the line. The flexible couplings installed during repair work will need to be bonded for this test, with a test station installed at the bonding location.

7. REGIONAL WATER QUALITY CONTROL BOARD REQUIREMENTS

Investigative Order No. R9-2007-0060 Item 4 calls for information about actions to prevent sewage discharge. Past actions as far as material selection were consistent with industry standards. The pipe material and polyethylene encasement appear to be state of the art for the construction period. It would not be uncommon for pipes of the same construction to have 50 to 100-year useful lives. In light of the untimely failure for this type and age of pipe, additional investigation to evaluate possible external corrosion elsewhere should be part of the City's SSO response plan. However, external corrosion at tears in the polyethylene encasement can not be easily detected. An electromagnetic conductivity (emag) survey of the soil along the alignment of the force main and any other iron pipes would provide information of similarly aggressive soils which could also result in pipeline failure. The emag provides a continuous plot of the soil conductivity over stationing or length. This procedure is typically done by sampling at 10-foot intervals so that virtually all of the alignment is evaluated. The emag survey uses radio frequency to evaluate soil conductivity (inverse of resistivity) and is non-intrusive. Cathodic protection can be installed to halt any further corrosion, but would not prevent failure of pipe that already had significant loss of metal. External or dig-up inspection of the entire alignment is not feasible. Conducting some excavation inspections and pipe condition assessments based on an emag survey would be prudent.

The Regional Board calls for a technical report that addresses the cause of the failure and the appropriateness of the material selection. The cause of the ductile iron pipe failure was most likely due to contact with severely corrosive soil moisture at holidays or tears and rips in the polyethylene encasement. The current version of AWWA C105, Appendix A suggests additional corrosion control beyond polyethylene encasement including application of cathodic protection in soils with high soil corrosivity test evaluation scores. The state of the art for the era the pipe was installed called for two choices: polyethylene encasement or leaving the pipe bare. Other pipe material systems, asbestos cement and reinforced plastic mortar, were used by the municipalities in the past and were abandoned. The ductile iron met the structural requirements of the force main.

In our opinion, it is unlikely that the force main was damaged during excavation and repair of an unknown irrigation line discovered buried 4-feet above the force main.

Future measures to prevent or mitigate future overflows would include replacement, lining, or cathodic protection and monitoring the cathodic protection in conjunction with periodic internal inspection.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

8. CLOSURE

Our services have been performed with the usual thoroughness and competence of the engineering profession. No other warranty or representation, expressed or implied, is included or intended.

SCHIFF ASSOCIATES

Robert Pannell
Sr. Corrosion Technologist
NACE International #5299

Graham E.C. Bell, Ph.D., P.E.
Cathodic Protection and Corrosion Specialist
NACE International #5350

Appendix A

Photographs from site visit and inspection April 3, 2007


2007 4 3


2007 4 3


2007 4 3


2007 4 3


KOMATSU
2007 4 3


260
2007 4 3


CAUTION
2007 4 3


CAUTION
2007 4 3


2007 4 3


2007 4 3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PIZZA
2007 4 3


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KOMATSU
PC 300 LC-7
C3
2007 4 3


CITY OF CARLSBAD
CALIFORNIA
2007 4 3

Appendix B

Laboratory Testing of Soil Samples

Table 1 - Laboratory Tests on Soil Samples

City of Carlsbad
24-inch DIP FM Failure, Carlsbad, CA
SA# 07-0477ENG
4-Apr-07

Sample ID			Gravel next to pipe	Soil from trench	Soil depth from exc. @ pipe
Resistivity		**Units**			
as-received		ohm-cm	560	116	128
saturated		ohm-cm	440	88	100
pH			7.4	8.3	8.1
Electrical Conductivity		mS/cm	1.35	5.75	3.36
Chemical Analyses					
Cations					
calcium	Ca^{2+}	mg/kg	279	270	134
magnesium	Mg^{2+}	mg/kg	131	384	118
sodium	Na^{1+}	mg/kg	836	6,100	3,737
potassium	K^{1+}	mg/kg	60	165	69
Anions					
carbonate	CO_3^{2-}	mg/kg	ND	ND	ND
bicarbonate	HCO_3^{1-}	mg/kg	552	488	433
flouride	F^{1-}	mg/kg	3.6	3.7	7.2
chloride	Cl^{1-}	mg/kg	928	7,980	5,150
sulfate	SO_4^{2-}	mg/kg	817	3,070	1,050
phosphate	PO_4^{3-}	mg/kg	3.4	ND	ND
Other Tests					
ammonium	NH_4^{1+}	mg/kg	42.2	ND	ND
nitrate	NO_3^{1-}	mg/kg	5.1	36.0	20.0
sulfide	S^{2-}	qual	Pos	Pos	Pos
Redox		mV	-503	-11	99

Electrical conductivity in millisiemens/cm and chemical analysis were made on a 1:5 soil-to-water extract.
mg/kg = milligrams per kilogram (parts per million) of dry soil.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed

Appendix C

Laboratory Testing of DIP samples

Bodycote

TESTING GROUP
www.bodycote.com
www.mtusa.bodycote.com

C E R T I F I C A T I O N

SUBMITTED BY: SCHIFF ASSOCIATES

431 WEST BASE LINE ROAD
CLAREMONT, CA 91711
ATTN: MARK BELL
LAB#: 06-04-SHA-07R Rev.2

DATE : 06/06/07
P. O. # : 07-0477ENG
SAMPLE ID: UPPER
INVOICE #: 644122
MATERIAL : DUCTILE IRON
PAGE # : 1 OF 1

SPECIFICATION: AWWA C151/A21.5-81.ED
WE SUBMIT THE FOLLOWING DETERMINATIONS:

NON-CONFORMING

"V" Notch Charpy Impact Test Results: Temp: ROOM

Sample Number	Impact Strength Foot-Pounds	Lateral Expansion Inches	% Shear
1	3.0	0.006	10
2	3.0	0.006	10
3	3.0	0.005	10
Average(Actual)	*3.0*		
Average(Adjusted)	*3.6*(Based on subsize specimens)		
Required, Minimum	7.0		
Actual Specimen size:	.332/.394 = 84%		

Cast Iron Microstructure: Information Only
Microstructure was evaluated IAW ASTM A247 castiron rating charts.
The results are as follows:

-OUTSIDE DIAMETER-
Types VII & IV IAW Plate I of ASTM A 247
Type A & B IAW Plate II of ASTM A 247
Size 4 - 6 IAW Plate III of ASTM A 247

-INSIDE DIAMETER-
Type I & II IAW Plate I of ASTM A 247
Plate II not applicable
Size 6 - 8 IAW Plate III of ASTM A 247

-CORE-
Type I & II IAW Plate I of ASTM A 247
Plate II not applicable
Size 6 - 8 IAW Plate III of ASTM A 247

TEST RESULTS DO NOT CONFORM TO SPECIFICATIONS. BODYCOTE MATERIALS TESTING, L.A.

Charpy test conducted in accordance with ASTM E23-06
Revised cert, changing disposition & adding specification
Ref. old LAB#: 05-22-SHA-126, Adding Micros & Photos

VICTOR S. FABIAN
Key Accounts Manager

The results reported herein relate only to the items tested. The test certification shall not be reproduced except in full, without the written approval of the laboratory. The recording of false, fictitious, or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Bodycote TESTING GROUP
www.bodycote.com
www.mtusa.bodycote.com

C E R T I F I C A T I O N

SUBMITTED BY: SCHIFF ASSOCIATES
431 WEST BASE LINE ROAD
CLAREMONT, CA 91711
ATTN: MARK BELL
LAB#: 06-04-SHA-09R Rev.2

DATE : 06/06/07
P. O. # : 07-0477ENG
SAMPLE ID: LOWER
INVOICE #: 644122
MATERIAL : DUCTILE IRON
PAGE # : 1 OF 1

SPECIFICATION: AWWA C151/A21.5-81.ED
WE SUBMIT THE FOLLOWING DETERMINATIONS:

NON-CONFORMING

"V" Notch Charpy Impact Test Results: Temp: ROOM

Sample Number	Impact Strength Foot-Pounds	Lateral Expansion Inches	% Shear
1	2.0	0.006	10
2	2.0	0.006	10
3	2.0	0.006	10
Average(Actual)	*2.0*		
Average(Adjusted)	*2.7*(Based on subsize specimens)		
Required Minimum	7.0		
Actual Specimen size:	.289/.394 = 73%		

Cast Iron Microstructure: Information Only
Microstructure was evaluated IAW ASTM A247 castiron rating charts.
The results are as follows:

-OUTSIDE DIAMETER-
Types VII & IV IAW Plate I of ASTM A 247
Type A & B IAW Plate II of ASTM A 247
Size 4 - 7 IAW Plate III of ASTM A 247

-INSIDE DIAMETER-
Type I & II IAW Plate I of ASTM A 247
Plate II not applicable
Size 6 - 8 IAW Plate III of ASTM A 247

-CORE-
Type I & II IAW Plate I of ASTM A 247
Plate II not applicable
Size 6 - 8 IAW Plate III of ASTM A 247

TEST RESULTS DO NOT CONFORM TO SPECIFICATIONS. BODYCOTE MATERIALS TESTING,L.A.

Charpy test conducted in accordance with ASTM E23-06
Revised cert, changing disposition & adding specification
Ref. old LAB#: 05-22-SHA-131, Adding Micros & Photos

VICTOR S. FABIAN
Key Accounts Manager

Bodycote

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C E R T I F I C A T I O N

SUBMITTED BY: SCHIFF ASSOCIATES

431 WEST BASE LINE ROAD
CLAREMONT, CA 91711
ATTN: MARK BELL
LAB#: 06-05-SHA-252

DATE : 06/06/07
P. O. # : 07-0477
SAMPLE ID: UPPER
INVOICE #: 644210
MATERIAL : DUCTILE IRON
PAGE # : 1 OF 1

SPECIFICATION: AWWA C151-76/A21.51-81
WE SUBMIT THE FOLLOWING DETERMINATIONS:

NON-CONFORMING

TENSION TEST RESULTS:
Elongation reported in % over 4d gauge length.

TEST TEMP: ROOM
YIELD: .2% OFFSET

SAMPLE IDENTIFICATION	DIMENSIONS IN.	YIELD LOAD LBS.	TENSILE LOAD LBS.	YIELD STRENGTH PSI	TENSILE STRENGTH PSI	ELONGATION %	REDUCTION OF AREA %	HARDNESS
AS SUPPLIED	.252	2,131	2,944	**42,700**	59,000	6.5		
MAXIMUM>>>								
MINIMUM>>>				42,000	60,000	10.0		

TEST RESULTS DO NOT CONFORM TO SPECIFICATIONS.

BODYCOTE MATERIALS TESTING,L.A.

BMA 6

JAMES HOLLMAN
Certification Supervisor PK

Tensile test conducted in accordance with ASTM E8-04

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C E R T I F I C A T I O N

SUBMITTED BY: SCHIFF ASSOCIATES

431 WEST BASE LINE ROAD
CLAREMONT, CA 91711
ATTN: MARK BELL
LAB#: 06-05-SHA-250

DATE : 06/06/07
P. O. # : 07-0477
SAMPLE ID: LOWER
INVOICE #: 644210
MATERIAL : DUCTILE IRON
PAGE # : 1 OF 1

SPECIFICATION: AWWA C151-76/A21.51-81
WE SUBMIT THE FOLLOWING DETERMINATIONS:

NON-CONFORMING

TENSION TEST RESULTS:
Elongation reported in % over 4d gauge length.

TEST TEMP: ROOM
YIELD: .2% OFFSET

SAMPLE IDENTIFICATION	DIMENSIONS IN.	YIELD LOAD LBS.	TENSILE LOAD LBS.	YIELD STRENGTH PSI	TENSILE STRENGTH PSI	ELONGATION %	REDUCTION OF AREA %	HARDNESS
AS SUPPLIED	.252	2,106	2,896	**42,200**	58,000	5.0		
MAXIMUM>>>								
MINIMUM>>>				42,000	60,000	10.0		

TEST RESULTS DO NOT CONFORM TO SPECIFICATIONS.

BODYCOTE MATERIALS TESTING, L.A.

BMA 6

JAMES HOLLMAN
Certification Supervisor PK

Tensile test conducted in accordance with ASTM E8-04

The results reported herein relate only to the items tested. The test certification shall not be reproduced except in full, without the written approval of the laboratory. The recording of false, fictitious, or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Bodycote Testing Group
9840 Alburtis Avenue • Santa Fe Springs • California • 90670 • USA • Tel: +1 (562) 801-5662 • Fax: +1 (562) 801-5660

Appendix D

Copy of AWWA C105-82 Standard

ANSI/AWWA C105/A21.5-82
[Revision of ANSI/AWWA C105-72 (R77)]

AMERICAN NATIONAL STANDARD

for

POLYETHYLENE ENCASEMENT FOR DUCTILE-IRON PIPING FOR WATER AND OTHER LIQUIDS

ADMINISTRATIVE SECRETARIAT

AMERICAN WATER WORKS ASSOCIATION

CO-SECRETARIATS

AMERICAN GAS ASSOCIATION
NEW ENGLAND WATER WORKS ASSOCIATION

First edition approved by American National Standards Institute, Inc., Dec. 27, 1972.
Revised edition approved by American National Standards Institute, Inc., May 26, 1982.

Published by
AMERICAN WATER WORKS ASSOCIATION
6666 West Quincy Avenue, Denver, Colorado 80235

American National Standard

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Committee Personnel

Subcommittee 4, Cast-Iron Pipe and Fittings, which reviewed this standard, had the following personnel at that time:

TROY F. STROUD, *Chairman*
KENNETH W. HENDERSON, *Vice-Chairman*

User Members	*Producer Members*
S. C. BAKER	A. M. HORTON
B. W. FRANKLIN	J. P. JOHNSON
K. W. HENDERSON	HAROLD KENNEDY JR.
R. C. HOLMAN	J. H. MILLER
M. G. HOOVER	J. H. SALE
D. A. LINCOLN	T. F. STROUD
W. H. SMITH	T. B. WRIGHT

Standards Committee A21, Cast-Iron Pipe and Fittings, which reviewed and approved this standard, had the following personnel at the time of approval:

ARNOLD M. TINKEY, *Chairman*
THOMAS D. HOLMES, *Vice-Chairman*
JOHN I. CAPITO, *Secretary*

Organization Represented	*Name of Representative*
American Gas Association	H. J. FORR
American Society for Testing and Materials	GEORGE LUCIW*
American Water Works Association	G. S. ALLEN
	R. A. ARTHUR
	D. R. BOYD
	J. I. CAPITO*
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*Nonvoting liaison

Committee Personnel (continued)

American Water Works Association	M. G. HOOVER
	R. J. KOCOL
	G. M. KRALIK
	D. M. KUKUK
	R. L. LEE
	J. H. MILLER
	W. H. SMITH
	A. M. TINKEY
	D. L. TIPPIN
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	L. W. WELLER
Canadian Standards Association	W. F. SEMENCHUK*
Ductile Iron Pipe Research Association	T. D. HOLMES
	HAROLD KENNEDY JR.
	P. I. MCGRATH JR.
	L. L. NEEPER
	T. F. STROUD
Manufacturers' Standardization Society of the Valve and Fittings Industry	T. C. JESTER
Naval Facilities Engineering Command	S. C. BAKER
New England Water Works Association	ALBERT HELT
Underwriters' Laboratories, Inc.	W. CAREY†
	L. J. DOSEDLO

*Nonvoting liaison
†Alternate

Table of Contents

Foreword

This foreword is for information only and is not a part of ANSI/AWWA C105.

I. History of Standard

In 1926, ASA (now ANSI) Committee A21, Cast-Iron Pipe and Fittings, was organized under the sponsorship of AGA, ASTM, AWWA, and NEWWA. The current sponsors are AGA, AWWA, and NEWWA, and the present scope of Committee A21 activity is standardization of specifications for cast-iron and ductile-iron pressure pipe for gas, water, and other liquids, and fittings for use with such pipe. These specifications are to include design, dimensions, materials, coatings, linings, joints, accessories, and methods of inspection and test.

In 1958, Committee A21 was reorganized. Subcommittees were established to study each group of standards in accordance with the review and revision policy of ASA (now ANSI). The present scope of Subcommittee 4, Coatings and Linings, is to review the matter of interior and exterior corrosion of gray and ductile-iron pipe and fittings and to draft standards for the interior and exterior protection of gray and ductile-iron pipe and fittings.

In accordance with this scope, Subcommittee 4 was charged with the responsibility for:

1. Development of standards on polyethylene encasement materials and their installation as corrosion protection, when required, for gray and ductile cast-iron pipe and fittings.
2. Development of procedures for the investigation of soil to determine when polyethylene protection is indicated.

In response to these assignments, Subcommittee 4 has:

1. Developed ANSI A21.5-1972 (AWWA C105-72), Standard for Polyethylene Encasement for Gray and Ductile Cast-Iron Piping for Water and Other Liquids.
2. Developed Appendix A outlining soil-investigation procedures.

In 1976, Subcommittee 4 reviewed the 1972 edition and submitted a recommendation to Committee A21 that the standard be reaffirmed without change from the 1972 edition, except for the updating of this foreword.

In 1981, Subcommittee 4 again reviewed the standard. The major revisions incorporated into the current edition as a result of that review are listed in Sec. VII of this foreword.

II. History of Polyethylene Encasement

Loose polyethylene encasement was first used experimentally in the United States for protection of cast-iron pipe in corrosive environments in 1951. The first field installation of polyethylene wrap on cast-iron pipe in an operating water system was in 1958 and consisted of about 600 ft (180 m) of 12-in. pipe installed in a waste-dump fill area. Since that time, hundreds of installations have been made in severely corrosive soils throughout the United States in pipe sizes ranging from 4–54 in. in diameter. Polyethylene encasement has been used as a soil-corrosion preventative in Canada, England, France, Germany, and several other countries since development of the procedure in the United States.

III. Research

Research by the Cast Iron Pipe Research Association (CIPRA)* on several severely corrosive test sites has indicated that polyethylene encasement provides a high degree of protection and results in minimal and generally insignificant exterior surface corrosion of gray and ductile cast-iron pipe thus protected.

Investigations of many field installations in which loose polyethylene encasement has been used as protection for gray and ductile cast-iron pipe against soil corrosion have confirmed CIPRA's findings with the experimental specimens. These field installations have further indicated that the dielectric capability of polyethylene provides shielding for gray and ductile cast-iron pipe against stray direct current at most levels encountered in the field.

IV. Useful Life of Polyethylene

Tests on polyethylene used in the protection of gray and ductile cast-iron pipe have shown that after 20 years of exposure to severely corrosive soils, strength loss and elongation reduction are insignificant. Studies by the Bureau of Reclamation of the US Department of the Interior† on polyethylene film used underground showed that tensile strength was nearly constant in a 7-yr test period and that elongation was only slightly affected. The Bureau's accelerated soil-burial testing (acceleration estimated to be five to ten times that of field conditions) showed polyethylene to be highly resistant to bacteriological deterioration.

V. Exposure to Sunlight

Prolonged exposure to sunlight will eventually deteriorate polyethylene film. Therefore, such exposure prior to backfilling the wrapped pipe should be kept to a minimum. If several weeks of exposure prior to backfilling are anticipated, Class C material should be used (see Sec. 5-3.1.1).

VI. Options

This standard includes certain options, which, if desired, must be specified. These options are:

1. Color of polyethylene material (Sec. 5-3).
2. Installation method—A, B, or C (Sec. 5-4)—if there is a preference.

VII. Major Revisions

The major revisions in this edition consist of the following:

1. Reference to gray cast-iron pipe in the title and throughout the standard was deleted because gray iron pipe is no longer produced in the United States.
2. Metric conversions of all dimensions are included in this standard. Metric dimensions are direct conversions of customary US inch-pound units and are not those specified in International Organization for Standardization (ISO) standards.

*CIPRA became the Ductile Iron Pipe Research Association in 1979.

†Laboratory and Field Investigations of Plastic Films, US Dept. of the Interior, Bureau of Reclamation, Rept. No. ChE-82 (Sept. 1968).

American National Standard for

Polyethylene Encasement for Ductile-Iron Piping for Water and Other Liquids

Sec. 5-1 Scope

This standard covers materials and installation procedures for polyethylene encasement to be applied to underground installations of ductile-iron pipe. This standard also may be used for polyethylene encasement of fittings, valves, and other appurtenances to ductile-iron pipe systems.

Sec. 5-2 Definition

5-2.1 *Polyethylene encasement:* The encasement of piping with polyethylene film in tube or sheet form.

Sec. 5-3 Materials

5-3.1 *Polyethylene.* Polyethylene film shall be manufactured of virgin polyethylene material conforming to the following requirements of ASTM Standard Specification D-1248-78—Polyethylene Plastics Molding and Extrusion Materials:

5-3.1.1 *Raw material used to manufacture polyethylene film.*
Type: I
Class: A (natural color) or C (black)
Grade: E-1
Flow rate (formerly melt index): 0.4 maximum
Dielectric strength: Volume resistivity, minimum ohm–cm^3 = 10^{15}

5-3.1.2 *Polyethylene film.*
Tensile strength: 1200 psi (8.3 MPa) minimum
Elongation: 300 percent minimum
Dielectric strength: 800 V/mil (31.5 V/μm) thickness minimum

5-3.2 *Thickness.* Polyethylene film shall have a minimum thickness of 0.008 in. (8 mil, or 200 μm). The minus tolerance on thickness shall not exceed 10 percent of the nominal thickness.

5-3.3 *Tube size or sheet width.* Tube size or sheet width for each pipe diameter shall be as listed in Table 5.1.

TABLE 5.1

Tube and Sheet Sizes

Nominal Pipe Diameter *in.*	Minimum Polyethylene Width *in. (cm)*	
	Flat Tube	Sheet
3	14 (35)	28 (70)
4	16 (41)	32 (82)
6	20 (51)	40 (102)
8	24 (61)	48 (122)
10	27 (69)	54 (137)
12	30 (76)	60 (152)
14	34 (86)	68 (172)
16	37 (94)	74 (188)
18	41 (104)	82 (208)
20	45 (114)	90 (229)
24	54 (137)	108 (274)
30	67 (170)	134 (340)
36	81 (206)	162 (411)
42	95 (241)	190 (483)
48	108 (274)	216 (549)
54	121 (307)	242 (615)

Sec. 5-4 Installation

5-4.1 *General.* The polyethylene encasement shall prevent contact between the pipe and the surrounding backfill and bedding material but is not intended to be a completely airtight and watertight enclosure. Overlaps shall be secured by the use of adhesive tape, plastic string, or any other material capable of holding the polyethylene encasement in place until backfilling operations are completed.

5-4.2 *Pipe.* This standard includes three different methods of installation of polyethylene encasement on pipe. Methods A and B are for use with polyethylene tubes and method C is for use with polyethylene sheets.

5-4.2.1 *Method A.* (Refer to Figure 5.1.) Cut polyethylene tube to a length approximately 2 ft (0.6 m) longer than that of the pipe section. Slip the tube around the pipe, centering it to provide a 1-ft (0.3-m) overlap on each adjacent pipe section, and bunching it accordion-fashion lengthwise until it clears the pipe ends.

Lower the pipe into the trench and make up the pipe joint with the preceding section of pipe. A shallow bell hole must be made at joints to facilitate installation of the polyethylene tube.

After assembling the pipe joint, make the overlap of the polyethylene tube. Pull the bunched polyethylene from the preceding length of pipe, slip it over the end of the new length of pipe, and secure it in place. Then slip the end of the polyethylene from the new pipe section over the end of the first wrap until it overlaps the joint at the end of the preceding length of pipe. Secure the overlap in place. Take up the slack width to make a snug, but not tight, fit along the barrel of the pipe, securing the fold at quarter points.

Repair any rips, punctures, or other damage to the polyethylene with adhesive tape or with a short length of polyethylene tube cut open, wrapped around the pipe, and secured in place. Proceed with installation of the next section of pipe in the same manner.

5-4.2.2 *Method B.* (Refer to Figure 5.2.) Cut polyethylene tube to a length approximately 1 ft (0.3 m) shorter than that of the pipe section. Slip the tube around the pipe, centering it to provide 6 in. (15 cm) of bare pipe at each end. Make polyethylene snug, but not tight; secure ends as described in Sec. 5-4.2.1.

Before making up a joint, slip a 3-ft (0.9-m) length of polyethylene tube over the end of the preceding pipe section, bunching it accordion-fashion lengthwise. After completing the joint, pull the 3-ft (0.9-m) length of polyethylene over the joint, overlapping the polyethylene previously installed on each adjacent section of pipe by at least 1 ft (0.3 m); make snug and secure each end as described in Sec. 5-4.2.1.

Repair any rips, punctures, or other damage to the polyethylene as described in Sec. 5-4.2.1. Proceed with installation of the next section of pipe in the same manner.

5-4.2.3 *Method C.* (Refer to Figure 5.3.) Cut polyethylene sheet to a length approximately 2 ft (0.6 m) longer than that of the pipe section. Center the cut length to provide a 1-ft (0.3-m) overlap on each adjacent pipe section, bunching it

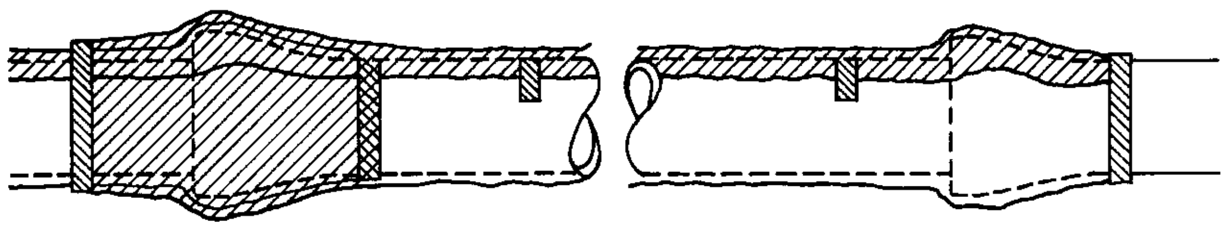

Figure 5.1. Method A: One length of polyethylene tube for each length of pipe, overlapped at joint.

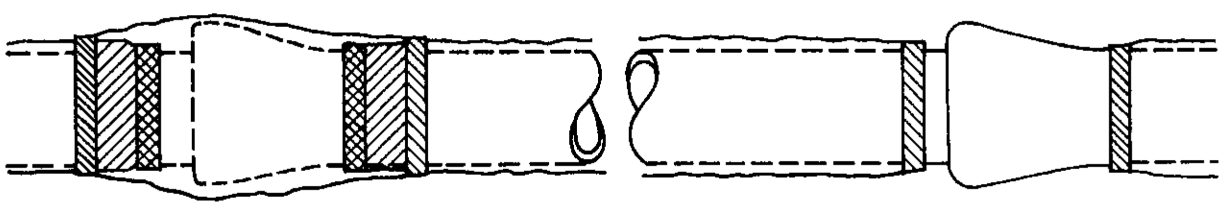

Figure 5.2. Method B: Separate pieces of polyethylene tube for barrel of pipe and for joints. Tube over joints overlaps tube encasing barrel.

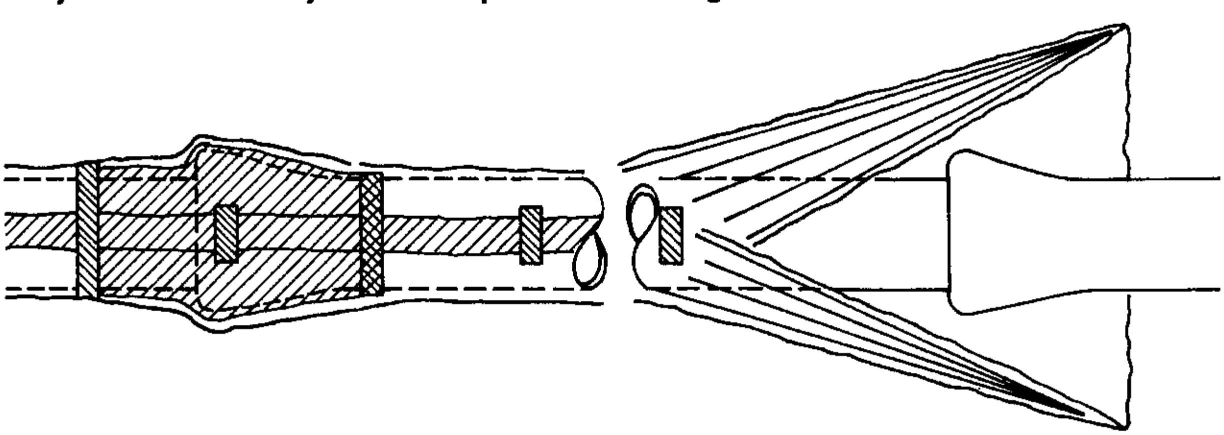

Figure 5.3. Method C: Pipeline completely wrapped with flat polyethylene sheet.

until it clears the pipe ends. Wrap the polyethylene around the pipe so that it circumferentially overlaps the top quadrant of the pipe. Secure the cut edge of polyethylene sheet at intervals of approximately 3 ft (0.9 m).

Lower the wrapped pipe into the trench and make up the pipe joint with the preceding section of pipe. A shallow bell hole must be made at joints to facilitate installation of the polyethylene. After completing the joint, make the overlap as described in Sec. 5-4.2.1.

Repair any rips, punctures, or other damage to the polyethylene as described in Sec. 5-4.2.1. Proceed with installation of the next section of pipe in the same manner.

5-4.3 *Pipe-shaped appurtenances.* Cover bends, reducers, offsets, and other pipe-shaped appurtenances with polyethylene in the same manner as the pipe.

5-4.4 *Odd-shaped appurtenances.* When valves, tees, crosses, and other odd-shaped pieces cannot be wrapped practically in a tube, wrap with a flat sheet or split length of polyethylene tube by passing the sheet under the appurtenance and bringing it up around the body. Make seams by bringing the edges together, folding over twice, and taping down. Handle width and overlaps at joints as described in Sec. 5-4.2.1. Tape polyethylene securely in place at valve-stem and other penetrations.

5-4.5 *Openings in encasement.* Provide openings for branches, service taps, blow-offs, air valves, and similar appurtenances by making an X-shaped cut in the polyethylene and temporarily folding back the film. After the appurtenance is installed, tape the slack securely to the appurtenance and repair the cut, as well as any other damaged areas in the polyethylene, with tape.

5-4.6 *Junctions between wrapped and unwrapped pipe.* Where polyethylene-wrapped pipe joins an adjacent pipe that is not wrapped, extend the polyethylene wrap to cover the adjacent pipe for a distance of at least 2 ft (0.6 m). Secure the end with circumferential turns of tape.

5-4.7 *Backfill for polyethylene-wrapped pipe.* Use the same backfill material as that specified for pipe without polyethylene wrapping, exercising care to prevent damage to the polyethylene wrapping when placing backfill. Backfill material shall be free from cinders, refuse, boulders, rocks, stones, or other material that could damage polyethylene. In general, backfilling practice should be in accordance with the latest revision of AWWA C600, Standard for Installation of Ductile-Iron Water Mains and Their Appurtenances.

Appendix A

Notes on Procedures for Soil Survey Tests and Observations and Their Interpretation to Determine Whether Polyethylene Encasement Should Be Used

This appendix is for information only and is not a part of ANSI/AWWA C105.

In the appraisal of soil and other conditions that affect the corrosion rate of gray and ductile cast-iron pipe, a minimum number of factors must be considered. They are outlined here. A method of evaluating and interpreting each factor and a method of weighing each factor to determine whether polyethylene encasement should be used are subsequently described.

Soil Survey Tests and Observations

1. Earth Resistivity
   - (a) Four-pin
   - (b) Single-probe
   - (c) Saturated-sample
2. pH
3. Oxidation-reduction (redox) potential
4. Sulfides
   - (a) Azide (qualitative)
5. Moisture content (relative)
   - (a) Prevalence
6. Soil description
   - (a) Particle size
   - (b) Uniformity
   - (c) Type
   - (d) Color
7. Potential stray direct current
   - (a) Nearby cathodic protection utilizing rectifiers
   - (b) Railroads (electric)
   - (c) Industrial equipment, including welding equipment
   - (d) Mine transportation equipment
8. Experience with existing installations in the area

1. *Earth resistivity.* There are three methods for determining earth resistivity: four-pin, single-probe, and soil-box. In the field, a four-pin determination should be made with pins spaced at approximate pipe depth. This method yields an average of resistivity from the surface to a depth equal to pin spacing. However, results are sometimes difficult to interpret where dry topsoil is underlain with wetter soils and where soil types vary with depth. The Wenner configuration is used in con-

nection with a soil resistivity meter, which is available with varying ranges of resistance. For all-around use, a unit with a capacity of up to 10^4 ohms is suggested because of its versatility in permitting both field and laboratory testing in most soils.

Because of the aforementioned difficulty in interpretation, the same unit may be used with a single-probe that yields resistivity at the point of the probe. A boring is made into the subsoil so that the probe may be pushed into the soil at the desired depth.

Inasmuch as the soil may not be typically wet, a sample should be removed for resistivity determination, which may be accomplished with any one of several laboratory units that permit the introduction of water to saturation, thus simulating saturated field conditions. Each of these units is used in conjunction with a soil resistivity meter.

Interpretation of resistivity results is extremely important. To base an opinion on a four-pin reading with dry topsoil averaged with wetter subsoil would probably result in an inaccurate premise. Only by reading the resistivity in soil at pipe depth can an accurate interpretation be made. Also, every effort should be made to determine the local situation concerning groundwater table, presence of shallow groundwater, and approximate percentage of time the soil is likely to be water saturated.

With gray and ductile cast-iron pipe, resistance to corrosion through products of corrosion is enhanced if there are dry periods during each year. Such periods seem to permit hardening or toughening of the corrosion scale or products, which then become impervious and serve as better insulators.

In making field determinations of resistivity, temperature is important. The result obtained increases as temperature decreases. As the water in the soil approaches freezing, resistivity increases greatly, and, therefore, is not reliable. Field determinations under frozen soil conditions should be avoided. Reliable results under such conditions can be obtained only by collection of suitable subsoil samples for analysis under laboratory conditions at a suitable temperature.

Interpretation of resistivity. Because of the wide variance in results obtained under the methods described, it is difficult specifically to interpret any single reading without knowing which method was used. It is proposed that interpretation be based on the lowest reading obtained, with consideration being given to other conditions, such as normal moisture content of the soil in question. Because of the lack of exact correlation between experiences and resistivity, it is necessary to assign ranges of resistivity rather than specific numbers. In Table A.1, points are assigned to various ranges of resistivity. These points, when considered along with points assigned to other soil characteristics, are meaningful.

2. *pH.* In the pH range of 0.0 to 4.0, the soil serves well as an electrolyte, and total acidity is important. In the pH range of 6.5 to 7.5, soil conditions are optimum for sulfate reduction. In the pH range of 8.5 to 14.0, soils are generally quite high in dissolved salts, yielding a low soil resistivity.

In testing pH, glass and reference electrodes are pushed into the soil sample and a direct reading is made, following suitable temperature setting on the instrument. Normal procedures are followed for standardization.

3. *Oxidation-reduction (redox) potential.* The oxidation-reduction (redox) potential of a soil is significant because the most common sulfate-reducing bacteria can live only under anaerobic conditions. A redox potential

greater than +100 mV shows the soil to be sufficiently aerated so that it will not support sulfate reducers. Potentials of 0 to +100 mV may or may not indicate anaerobic conditions; however, a negative redox potential definitely indicates anaerobic conditions under which sulfate reducers thrive. This test also is accomplished using a pH meter, with platinum and reference electrodes inserted into the soil sample, which permits a reading of potential between the two electrodes. It should be noted that soil samples removed from a boring or excavation can undergo a change in redox potential on exposure to air. Such samples should be tested immediately on removal from the excavation. Experience has shown that heavy clays, muck, and organic soils are often anaerobic, and these soils should be regarded as potentially corrosive.

TABLE A.1

*Soil-Test Evaluation**

Soil Characteristics	Points
Resistivity—*ohm-cm* (based on single-probe at pipe depth or water-saturated soil box):	
<700	10
700-1000	8
1000-1200	5
1200-1500	2
1500-2000	1
>2000	0
pH:	
0-2	5
2-4	3
4-6.5	0
6.5-7.5	0†
7.5-8.5	0
>8.5	3
Redox potential:	
>+100 mV	0
+50 to +100 mV	3.5
0 to +50 mV	4
Negative	5
Sulfides:	
Positive	3.5
Trace	2
Negative	0
Moisture:	
Poor drainage, continuously wet	2
Fair drainage, generally moist	1
Good drainage, generally dry	0

*Ten points—corrosive to gray or ductile cast-iron pipe; protection is indicated.

†If sulfides are present and low or negative redox-potential results are obtained, three points shall be given for this range.

4. *Sulfides.* The sulfide determination is recommended because of its field expediency. A positive sulfide reaction reveals a potential problem due to sulfate-reducing bacteria. The sodium azide–iodine qualitative test is used. In this determination, a solution of 3 percent sodium azide in a 0.1 *N* iodine solution is introduced into a test tube containing a sample of the soil in question. Sulfides catalyze the reaction between sodium azide and iodine, with the resulting evolution of nitrogen. If strong bubbling or foaming results, sulfides are present, and the presence of sulfate-reducing bacteria is indicated. If very slight bubbling is noted, sulfides are probably present in small concentration, and the result is noted as a trace.

5. *Moisture content.* Since prevailing moisture content is extremely important to all soil corrosion, every effort must be made to determine this condition. It is not proposed, however, to determine specific moisture content of a soil sample, because of the probability that content varies throughout the year, but to question local authorities who are able to observe the conditions many times during the year. (Although mentioned under item 1, Earth Resistivity, this variability factor is being reiterated to emphasize the importance of notation.)

6. *Soil description.* In each investigation, soil types should be completely described. The description should include

color and physical characteristics, such as particle size, plasticity, friability, and uniformity. Observation and testing will reveal whether the soil is high in organic content; this should be noted. Experience has shown that in a given area, corrosivity may often be reflected in certain types and colors of soil. This information is valuable for future investigations or for determining the most likely soils to suspect. Soil uniformity is important because of the possible development of local corrosion cells due to the difference in potential between unlike soil types, both of which are in contact with the pipe. The same is true for uniformity of aeration. If one segment of soil contains more oxygen than a neighboring segment, a corrosion cell can develop from the difference in potential. This cell is known as a differential aeration cell.

There are several basic types of soils that should be noted: sand, loam, silt, clay, muck. Unusual soils, such as peat or soils high in foreign material, also should be noted and described.

7. *Potential stray direct current.* Any soil survey should include consideration of possible stray direct current with which the gray or ductile cast-iron pipe installation might interfere. The widespread use of rectifiers and ground beds for cathodic protection of underground structures has resulted in a considerable threat from this source. Proximity of such cathodic protection systems should be noted. Among other potential sources of stray direct current are electric railways, industrial equipment (including welding equipment), and mine-transportation equipment.

8. *Experience with existing installations.* The best information on corrosivity of soil with respect to gray and ductile cast-iron pipe is the result of experience with these materials in the area in question. Every effort should be made to acquire such data by questioning local officials and, if possible, by actually observing existing installations.

Soil-Test Evaluation

When the soil-test procedures described herein are employed, the following tests are considered in evaluating corrosivity of the soil: resistivity, pH, redox potential, sulfides, and moisture. For each of these tests, results are categorized according to their contribution to corrosivity. Points are assigned based on experience with gray and ductile cast-iron pipe. When results of these five test-observations are available, the assigned points are totaled. If the sum is equal to ten or more, the soil is corrosive to gray or ductile cast-iron pipe, and protection against exterior corrosion should be provided. This system is limited to soil corrosion and does not include consideration of stray direct current. Table A.1 lists points assigned to the various test results.

General. These notes deal only with gray and ductile cast-iron pipe, the soil environment in which they will serve, and methods of determining a need for polyethylene encasement.